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INTERIM REPORT ON NEL PROBLEM L6-3

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EXPERIMENTAL DEEP OCEAN ACOUSTIC TRANSPONDER

by

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Robert Lyndall/McFarland

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Abstract

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To fill the apparent need for supplemental navigation aids for submarines transiting the Arctic region, a long-lived acoustic transponder is being developed by NEL. This transponder is compatible with equipments on the nuclear-powered under-ice submarines (AN/SQS-4, AN/BQS-4A, and AN/BQR-2B) and offers a semi-secure navigational reference point. Work has been initiated to power the transponder with a nuclear isotopic power supply (SNAP program) in order that reliable long operating life is achieved. ↗

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This interim report contains the results and recommendations of both the feasibility study and the experimental work and is a record of work on NEL Problem L6-3 which is continuing.

Submarines transiting the Arctic Ocean have a requirement for navigation aids which supplement their inertial navigation equipment (SINS) and their gyro compass. Because of the dependency of the submarine on its own navigational equipment, it is desirable to supplement, if at all possible, the existing shipboard equipment with additional navigational aids. With external navigational aids working in conjunction with existing shipboard equipment such as the AN/BQS-4A, AN/SQS-4, AN/BQS-6, and the AN/BQR-2B, a valuable navigational capability could be realized. In addition, re-alignment or recalibration of the SINS and other plots would be possible without visual fixes, which in fact are not always available in the Arctic environment. Furthermore, in many tactical situations, it will be preferable to avoid surfacing, if possible, because of the obvious dangers of the surfacing action, and the possible breach of otherwise 100% security. For non-emergency situations, an underwater acoustic transponder would give a positional reference permitting simple, quick and relatively secure rendezvous.

The initial phase of the study was made to determine the required operating parameters of such a semi-secure acoustic device and problems

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related to the achievement of such desired operating characteristics. This was done to establish a relative reference base for comparison of the magnitude of the various but related aspects of difficulty, expense, vulnerability, etc., and to insure that any concept proposed would be based upon firm ground from the standpoints of economy, technology, and operational utility. The concept of using sea floor mounted acoustic transponders powered by nuclear isotope power supplies is feasible and appears to have considerable merit.

Because the requirements as envisioned by the operational submarine forces are quite stringent as they relate to the functional capabilities of the transponder, it is necessary to review each one thoroughly before drawing any conclusions.

Tentative specific requirements for the Arctic Ocean Navigation Transponder are:

1. Operating depth capability - 6000 feet.
2. Compatible with the AN/SQS-4, AN/BQS-4A, (AN/BQS-6), and AN/BQR-2B.
3. Life expectancy of one year minimum.
4. Compact and rugged enough to be ejected from a torpedo tube.
5. Acquisition range of at least 10 kiloyards.

Items 2, 3, and 5 determine the parameters of the electro-acoustic portion of the transponder. Item 2 resolves the interrogating bandwidth to 6-8 kc/s (except for the AN/BQS-6 which operates around 3.5 kc/s). In addition, the usable interrogating signal level at 10 kiloyards may

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be determined from the equipment parameters. The reply band of the transponder is governed by the frequency capabilities of the AN/BQR-2B passive listening equipment, signal attenuation coefficients and practical aspects of transducer design and efficiency. Also, the power level of the transponder is determined by the detection sensitivity and processing capabilities of this equipment. Graphs which show the expected range based upon the parameters of the sonar equipments on the submarines are shown as Figures 14 and 15. These graphs give the performance of the transponder based upon ship's equipment operating up to or very near the equipment specifications. The translation frequency increment is chosen to be compatible with not only the transponder transducers, but also the receiving capability of the BQR-2B. These figures show that 10 kiloyards is a probable upper limit of the range of detection, and a more conservative figure might be 8 kiloyards. The acoustic power output of the transponder also determines the type of prime power or energy source, but this requirement will be discussed more fully later in the report.

Before a complete discussion of the transponder's characteristics can be initiated, it is necessary to form an idea about the mechanical configuration for initial study phase and then to increase or decrease the requirements as may be possible. Items 1 and 4 are the primary contributing factors toward the mechanical design of the transponder with the greatest emphasis being initially placed upon depth of operation and ejectability. With the prerequisites outlined, a

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physical concept meeting these requirements is shown in figures 2, 3, and 4. From this configuration, work was initiated to carry the concept to experimental hardware.

A study of components capable of operating at 6000 feet was made to determine if the requested operating capabilities could be met. The major problems in this would be the transponder transducers, the floatation material, the cable for the transducers, and the pressure vessel (possible failure due to corrosion), and connectors.

Transducers capable of operating at 6000 feet had been designed and tested for use with the AN/UQC which operates in the approximate frequency range desired. These transducers are very efficient (50-65%) thereby reducing the electrical load on the power source. The directivity index of these units is compatible with the design requirements for both horizontal and vertical beam widths. (See Figures 17, 18, 19, and 20.) With BUSHIPS approved "blocked cable", such as DSS-2 or 3, it appears that these transducers will do the job very well without further development time or expense. In addition, several types of underwater connectors exist which appear to have the necessary operating characteristics for use in deep water.

Extensive electronic design has been completed on the required hardware following the precepts which were proven in the shallow-water, short-range transponders for minehunting applications. NEL Problem A3-3. This earlier work was completed and reported upon in NEL Report 1076 by N. C. Kelly, R. L. McFarland and J. W. Sampsell.

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The electronic and acoustic characteristics of the transponder have been dock tested and also tested with an SSN to determine its compatibility with existing fleet equipment. The transponder may be interrogated in the 6-8 kc/s band. The displacement frequency is 4.5 kc/s which gives a reply frequency band of 10.5-12.5 kc/s. With these parameters, it was possible to achieve a receive sensitivity of 9 db above 1 μ bar for lock up with the hydrophone and transponder circuitry. Especially designed bandpass filters with 80 db suppression of sidebands permitted us to employ a source level of 90 db above 1 μ bar re 1 meter. This was achieved with a 35 watt transistorized power amplifier. All of the transponder active circuitry is transistorized. In the quiescent state, the transponder draws 20 milli-amperes at 12-18 volts DC. For full acoustic power output, the transponder draws 1.5 amperes at 30 volts DC. These current levels are compatible with the characteristics of the Number 6 dry cell which is employed in the battery pack. For actual circuit configuration, Figures 7 and 7a are the schematics for the NEL Frequency Displacement Transponder. Figures 8 and 8a are for a proposed Time-Delay Frequency Displaced Transponder. The results of the testing with the SSN are as follows:

6.4 kc/s Interrogation Level	Battery Current	10.9 kc/s Reply Level
-10 db re 1 μ bar	50 milli-amperes	71 db above 1 μ bar re 1 meter
1 db re 1 μ bar	5 amperes	81 db above 1 μ bar re 1 meter
6 db re 1 μ bar	1 ampere	87 db above 1 μ bar re 1 meter
9 db re 1 μ bar	1.5 amperes	90 db above 1 μ bar re 1 meter

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Because these tests were conducted in San Diego bay while the SSN was berthed, a physical separation of the transponder and the submarine greater than 1100 yards was not possible. Additional testing in the open ocean is scheduled; and from the results in the bay, detection performance should be that predicted by Figure 15.

Probably the most difficult requirement to be met is the requirement for one year's useful life. With the design goal of a minimum life of one year, and more if at all possible, a thorough investigation of energy sources was made. Operational lifetime in excess of one year would greatly offset the logistic expenses involved in the placement of the transponder.

A review of the readily available energy sources of the required power levels, proper size and temperature characteristics showed the Le Clanche cell (dry battery) to be useful for lifetimes of one year or less. The lifetime of one year would be marginal, but feasible. At this time only the SNAP (Systems for Nuclear Auxiliary Power) isotopic type supply appears capable of meeting the reliable, long lifetime requirements desired for the transponder. Such units have been developed and tested under adverse conditions and their merit has been exhibited by their reliability in several installations (Arctic weather station, unmanned, Antarctic weather station, Chesapeake Bay light buoy, and Gulf of Mexico weather station, etc.).

Inquiry as to the availability of this type of power supply was initiated from our laboratory through BUSHIPS Code 342B to the

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Atomic Energy Commission in 1962. After conferences with representatives of the respective agencies, it was agreed that the proposed application merited consideration and support. Therefore, the Isotopic Power Branch, Division of Reactor Development, U. S. Atomic Energy Commission initiated contracts for the development of a SNAP supply to fulfill our operating requirements. Two contracts have been let for the developmental program of the power supplies to the Nuclear Division of the Martin Company and also to the Minnesota Mining and Manufacturing Co. Both are two phase contracts, with study phase and actual developmental phase with usable power supplies coming out of the contracts. It is hoped that the resultant SNAP power supplies will give an operating life time greatly in excess of two years (probably five years). Such a lifetime implies extreme reliability and during the conferences held by the agency representatives, it was stated that the reliability could be greatly enhanced if a single contractor handled the construction of the entire assembly, including nuclear isotope power supply and the electro-acoustic portions of the transponder, rather than multiple contractors or combination contractor-laboratory in-house construction.

While the development of the SNAP power supplies continues, work at NEL is also being continued toward the implementation of at least one battery powered unit for testing and evaluation. Photographs of the experimental transponder, Figures 9, 10, 11, 12, and 13, show the status of the program at this time. The battery-powered transponder will have a designed maximum life of one year, while operating at a

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temperature of 38° Farenheit. Extreme changes in the ambient temperature level will have a marked effect upon the lifetime capability of the battery pack. This one year life is premised on the likely operational case of relatively few interrogations and long term quiescent operation.

Three major problems are met in the mechanical design: The pressure vessel, the floatation section, and the separation device.

The pressure vessel of the experimental transponder is limited in both size and weight. These limitations impose very demanding requirements upon the type of materials to be considered for the pressure vessel. Only high strength alloys offer adequate strength-weight ratio for use in a torpedo tube launched transponder. This requirement has been circumvented during the experimental program this far by the use of surplus torpedo air-flasks for the pressure vessel hull in the experimental battery powered transponder.

Floatation material for operation at 6000 feet has traditionally been pliable bags or drums filled with high octane gasoline, but these operations have always been from a surface vessel and are not attractive to a submarine. Floatation material carried internally in a submarine should be of the non-hazardous variety to prevent any catastrophes. Materials with the capability of withstanding high hydrostatic pressure and possessing buoyant properties are not numerous. Several types of floatation could be employed without using gasoline, but they would be subject to rupture and, therefore, failure of the device. These designs are spherical metal floats, glass spherical

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floats (net floats), metal floats filled with lithium, and honey combed metal floats. One type of floatation which possesses all the water inertness and rupture proof qualities is one constructed of solid material. Solids which possess both the quality of strength and a specific gravity of less than one are not commonplace. An epoxy filled with glass microspheres (hollow glass spheres 30-300 microns in diameter) has the proper characteristics. This epoxy composite has a weight of 42-44 pounds per cubic foot, giving 20-22 pounds of positive buoyancy per cubic foot less the weight of the mechanical constraint.

With initial breadboarding, dockside testing, and San Diego Bay testing completed, work was initiated on the construction of a full scale experimental battery powered transponder. The enclosed photographs show the mechanical configuration and the present state of the work. Sea testing has been completed at this time, because all of the pressure sensitive portions of the transponder have not yet been tested. When the pressure testing has been completed and a suitable launch platform is available, testing of the experimental transponder's mechanical configuration will begin. After satisfactory completion of the mechanical configuration, sea testing of the entire transponder will be conducted. These tests will give a thorough checkout on all units of the transponder, transducers, mechanical packaging, and the electronics.

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Recommendations:

1. Continue work on the battery powered transponder at USNEL.
2. Procure on USAEC's power supply contract a like number of transponders (electro-acoustic, mechanical packaging). This will require support from the Bureau of Ships, USNEL, and USAEC.
3. Review the parameters of the transponder and determine its suitability for modification for use with the AN/BQS-6, when submarines having such equipment are fitted for Arctic operation.

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APPENDIX

Transponder

In establishing some of the preliminary design parameters as a basis for experimental development of sonar navigation aids, we have considered some of the characteristics and techniques applicable to acoustic transponders. If appreciable gain in return signal is to be realized, it would appear mandatory that some parameter be specially considered; i.e., time, direction, frequency, position (separation), etc. For example: (a) In the time shared transponder, the signal is delayed and/or interpreted for a short period. It is then amplified and transmitted, during which time interval the receiver may be made insensitive. The transmitted signal may be the amplified received signal or a synthetic internally generated signal. (b) In the directional transponder, simultaneous reception and transmission of the signal with adequate gain is achieved (with stability), whenever the gain is not greater than the electrical and/or acoustical isolation between the hydrophone and projector. Such isolation is obtained by introducing directivity into the beam patterns of the transponder's transducers, and by minimizing mechanical coupling through common mounting hardware. (c) Isolation by the position (separation) parameter would imply omnidirectional hydrophone and projector units distributed in space to obtain the necessary isolation by the inverse

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square loss (spreading loss). The large separation and the necessarily exposed interconnections of the hydrophone-projector units are as a rule undesirable for most applications where separation alone is considered. This parameter (position) is often shared with one of the other types to some degree, and is usually found in the directional type. (d) The fourth and final type of transponder to be considered is the frequency displacement type whose useful gain can be further enhanced by appropriate filtering in the electronic circuitry, providing an additional high degree of rejection of the transmitted signals by the receiver. Such frequency displacement combined with other parameters (directivity, separation, etc.) is being used in this development transponder to increase the total amount of isolation obtainable.

In the course of the study phase and experimental work, the frequency displacement technique has shown the greatest promise. In addition to the previously mentioned performance advantages, such a design also provides an order of security merely by virtue of the fact that it must be interrogated at one frequency and replies received at a displaced frequency. If greater security than this is desired, such can readily be incorporated by moderate sophistication in the circuitry to incorporate pulse-time coding as an additional, selective parameter. The existing equipment, being interrogated by existing, shipboard sonar (AN/BQS-4, AN/BQS-4A), and replies being received on existing shipboard equipment (AN/BQR-2B) requires the addition of only a simple internal timer to serve as the range-readout. It may also be desirable to

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provide some additional filtering for the input of the AN/BQR-2 to improve the operation under conditions of high, ambient noise (The Arctic is generally a quiet environment.). This interval timer will be calibrated directly into yards for instantaneous plotting of the submarine's position.

The frequency translation technique also has another advantage in that it will not interfere with the normal echo-ranging capabilities of the AN/BQS-4A, that is no clutter will be seen on the display of the sonar due to the transponder's reply.

Self triggering will also be avoided with proper choice of the frequency displacement and separation of the hydrophone and projector.

The following graphs, sketches, and photographs will help to illustrate the design of the transponder. In addition, a list of the operating characteristics is included.

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List of Figures

Operating Characteristics

Figure 1 Operating characteristics, list of

Sketches

Figure 2 Complete transponder

Figure 3 Implanted transponder

Figure 4 Cross section of transponder

Block Diagrams

Figure 5 Block diagram of frequency displacement transponder

Figure 6 Block diagram of time-delay and frequency displacement transponder (Proposed)

Schematic Diagrams

Figure 7 Schematic of frequency displacement transponder

Figure 7a Schematic of frequency displacement transponder power amplifier

Figure 8 Schematic of time delay and frequency displaced transponder (Proposed)

Figure 8a Schematic of time delay and frequency displaced transponder power amplifier (Proposed)

Photographs

Figure 9 Photograph of experimental battery powered transponder

Figure 10 Photograph of exploded view of experimental transponder

Figure 11 Photograph of transducers, electronics, and battery pack

Figure 12 Photograph of separation ring

Figure 13 Photograph of transponder with engineer to show relative size of experimental transponder

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Curves

- Figure 14 Interrogating sonar performance
- Figure 15 Calculated transponder performance
- Figure 16 Hydrophone sensitivity curve
- Figure 17 Hydrophone horizontal beam pattern
- Figure 18 Hydrophone vertical beam pattern
- Figure 19 Projector horizontal beam pattern
- Figure 20 Projector vertical beam pattern
- Figure 21 Projector transmitting response

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List of Operating Characteristics

	Frequency Displacement	Time Delay (Proposed)
Interrogation Frequency Band	6-8 kc/s	6-8 kc/s
Reply Frequency Band	10.5-12.5 kc/s	11.5 kc/s
Frequency Displacement	4.5 kc/s	
Sensitivity	9 db above 1 microbar	Same
Maximum Acoustic Power Output	90 db above 1 microbar re 1 meter	Same
Horizontal Pattern	Symmetrical (See Figures 16 and 18)	Same
Vertical Pattern	See patterns (Figures 19 and 20)	Same
Power Supply (Experimental model)	Number 6 dry cells in series-parallel	Same
Power Supply (Contractor model)	Nuclear Isotope	Same
Operating Time	Absolute maximum of ¹ one year - battery powered	Same
Operating Time	2 years minimum-Isotope powered (Probable 5 years)	
Maximum Depth (Experimental model)	2600 feet ²	
Maximum Depth (Contractor model)	10,000 feet	

Physical Dimensions

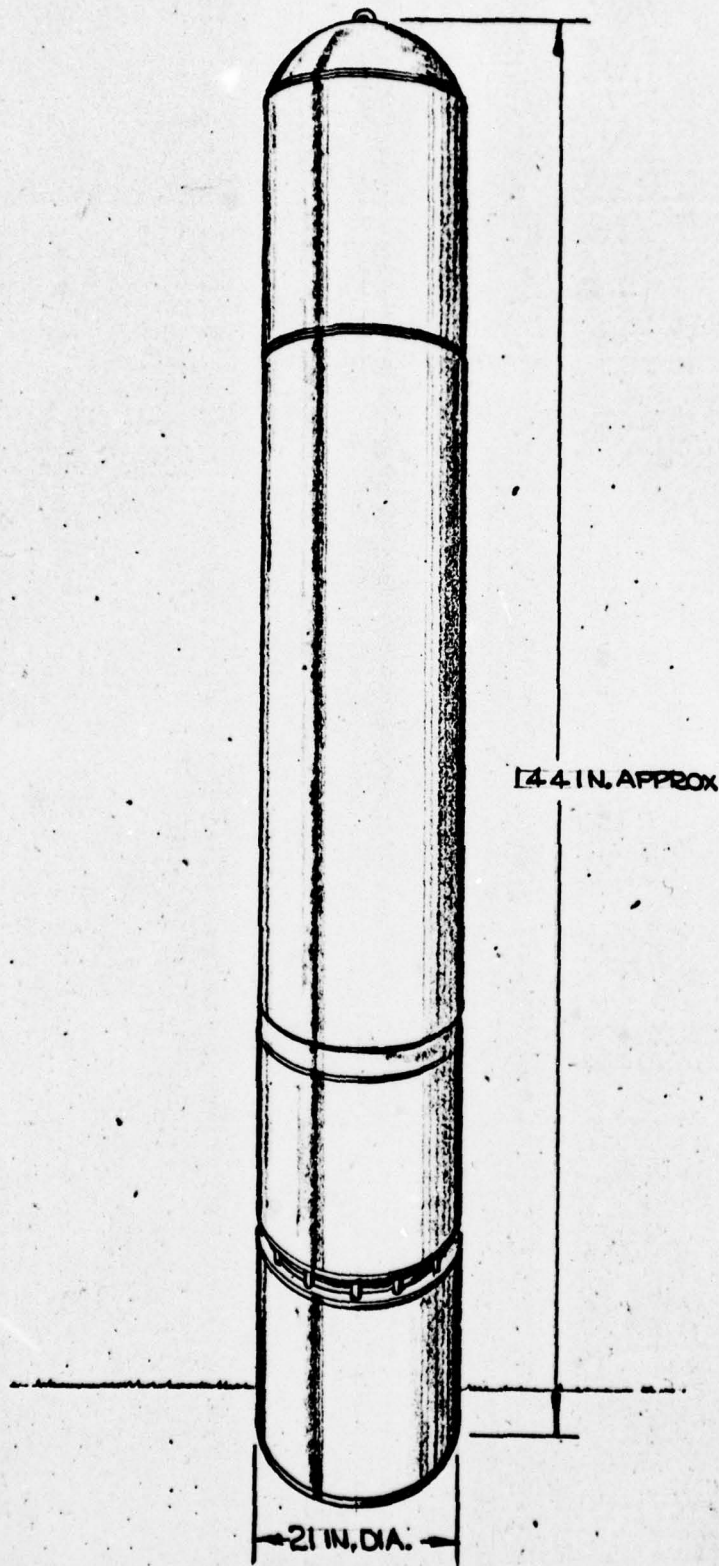
Length	164 inches
Diameter	21 inches
Weight	1600 pounds

Figure 1

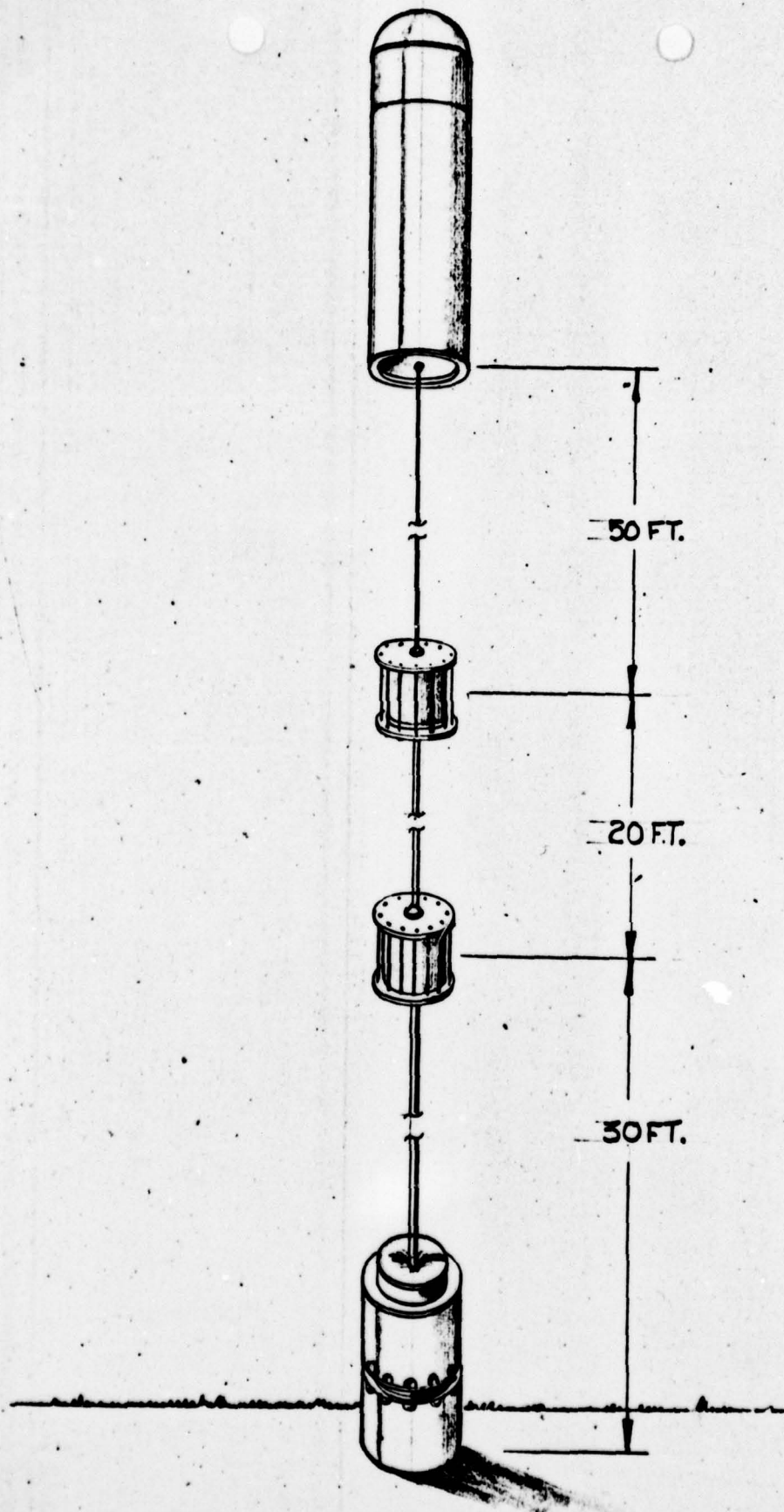
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1. The quiescent current drain on the power pack is 20 milli-amperes. When interrogated, the current drain on the power pack is 2 amperes at maximum signal level.

2. Because the pressure testing facilities at NEL for large items are limited to 1100 psi, the maximum operating depth is no greater than test pressure. Some of the smaller portions of the transponder have been tested to 5000 psi.



— DEEP OCEAN NAVIGATION TRANSPONDER —



DONT
DEPLOYED DEEP OCEAN NAVIGATION TRANSPONDER

6
NEL 62

HEMISPHERICAL NOSE
FILL WITH STYCAST
OR EQUIV. -GLASS
MICROSPHERES

UPPER CYLINDER
SECTION FILL WITH
STYCAST OR EQUIV.
-GLASS MICROSPHERES

COMPLIANT RING

SUSPENSION LINE
CENTERING RING
RELEASE TO CYL. END

TRANSDUCER #1

20 FT. 2 COND.
SHIELDED WRAP ON
SEPARABLE SPINNING
SPOOL - CABLE HAS
OUTSIDE STRAIN WRAP

TRANSDUCER #2

30 FT. 2 PAIR SHIELDED
OUTSIDE STRAIN WRAP
WRAP ON SEPARABLE
SPINNING SPOOL

CABLE BELL MOUTH

LANYARD-TRIGGERS
SEPARATION RING

HOUSING FOR
NUCLEAR PACKAGE

HANDLING RING

STRESS ROD

SUFFICIENT POLYPROPYLENE
LINE TO POSITION CENTERING
RING AT BOTTOM OF HOUSING

50 FT. POLYPROPYLENE
LINE WRAP ON SEPARABLE
SPINNING SPOOL

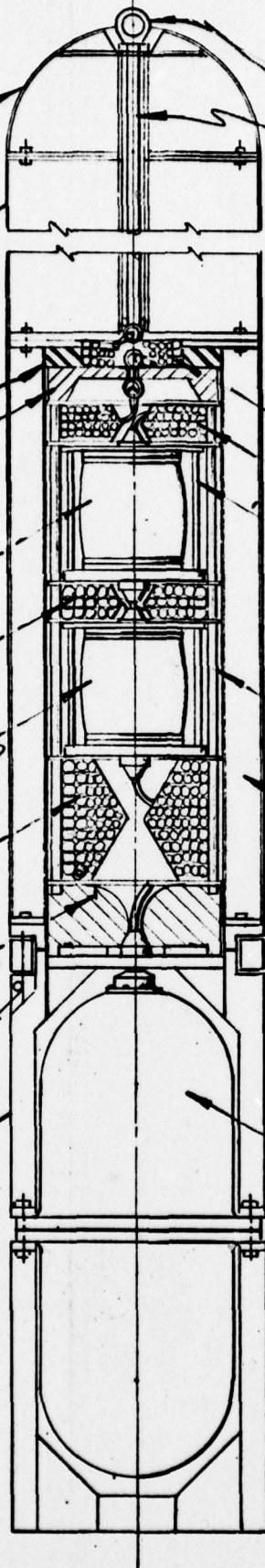
TRANSDUCER CLAMP ROD (TYP.)

PLASTIC ASSEMBLY ROD (TYP.)
(EXPENDABLE)

HOUSING - STIFFEN WITH
HAT SECTIONS - FILL WITH
STYCAST OR EQUIV. -GLASS
MICROSPHERES

SEPARATION RING

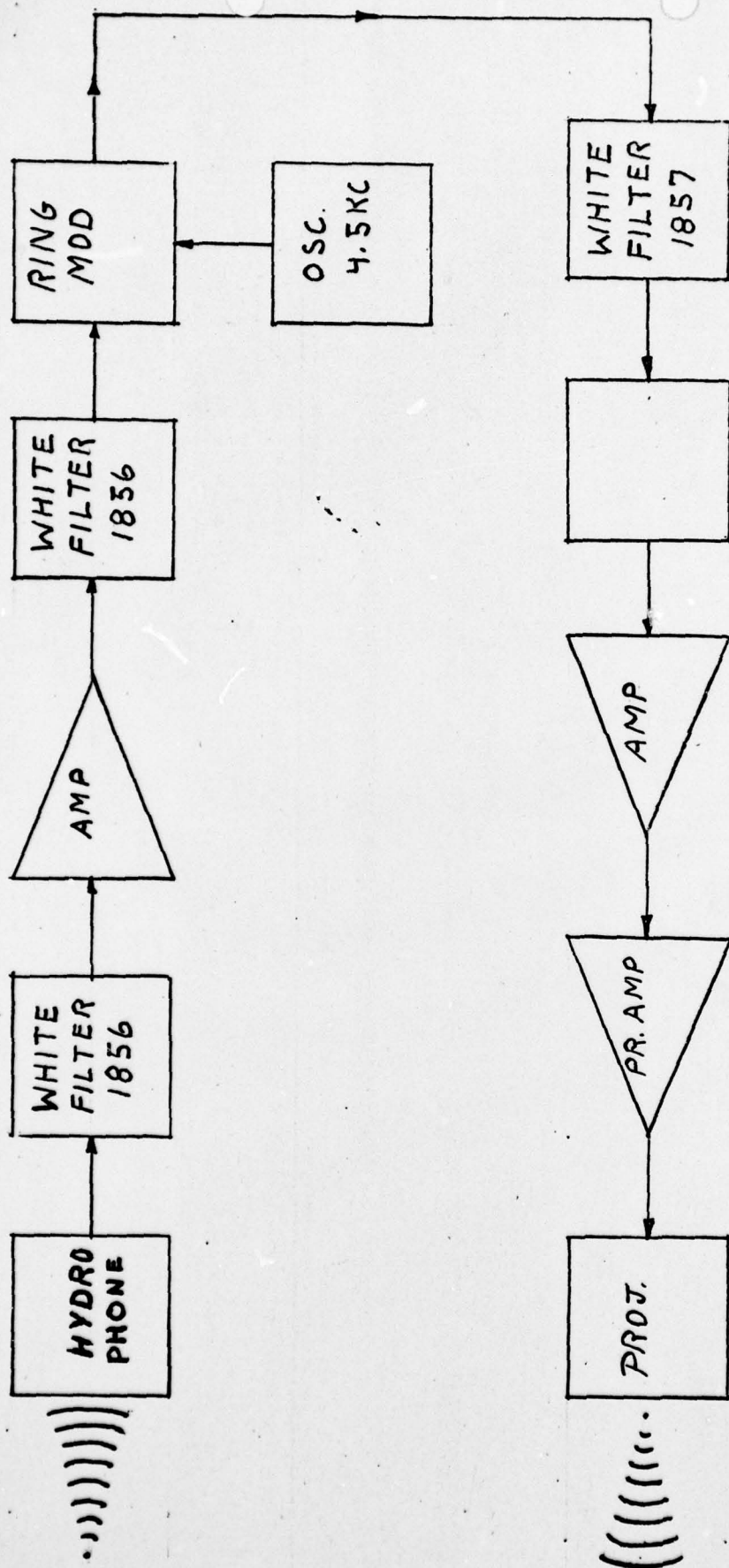
NUCLEAR GENERATOR
AND ELECTRONIC
CIRCUITRY - PRESSURE VESSEL



DEEP OCEAN NAVIGATION TRANSPONDER
PROPOSED PACKAGING

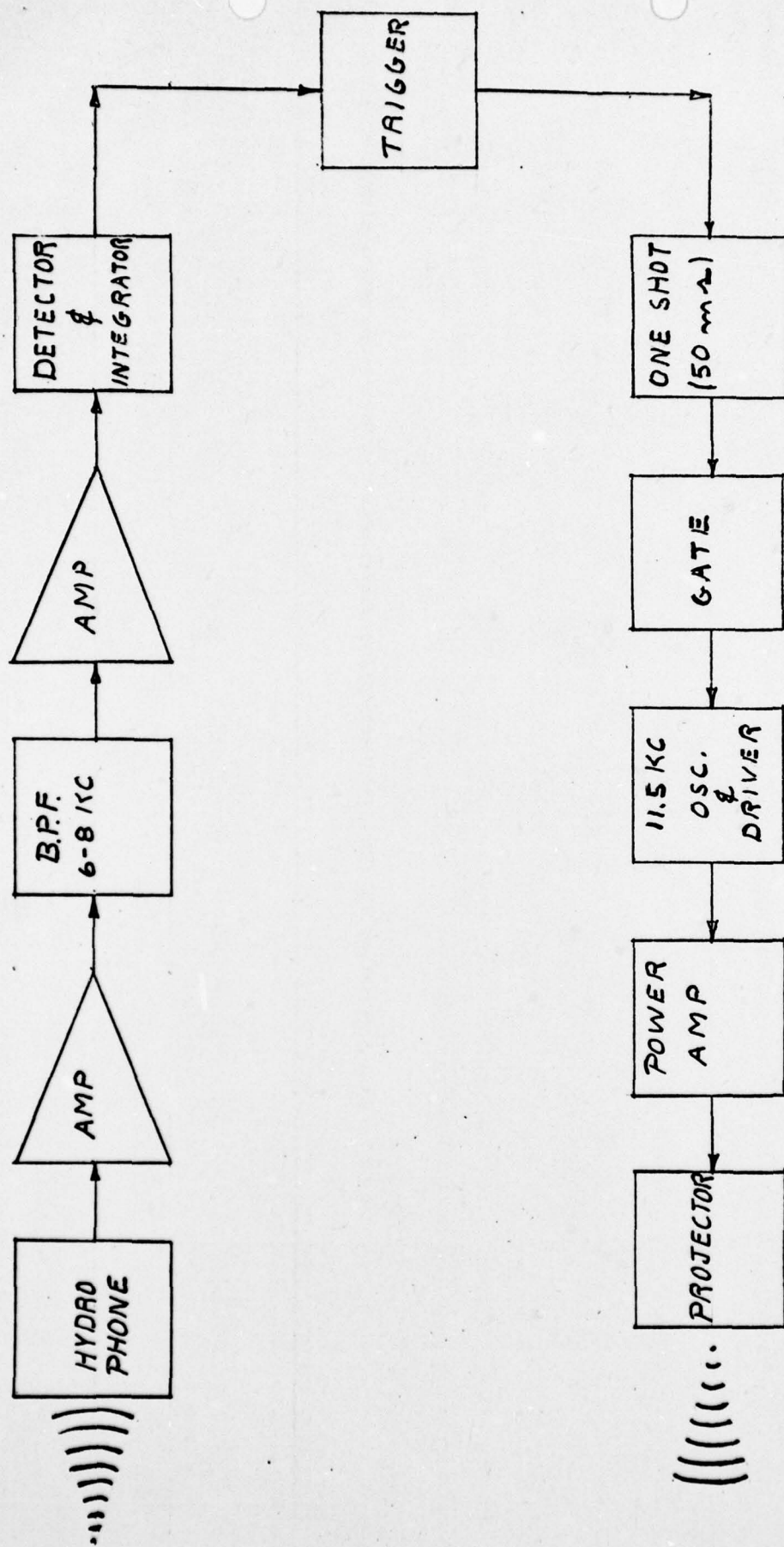
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NEL 63

NEL. FREQUENCY DISPLACEMENT TRANSPONDER

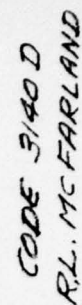


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TIME DELAY & FREQ. DISPLACED TRANSPONDER (PROPOSED)

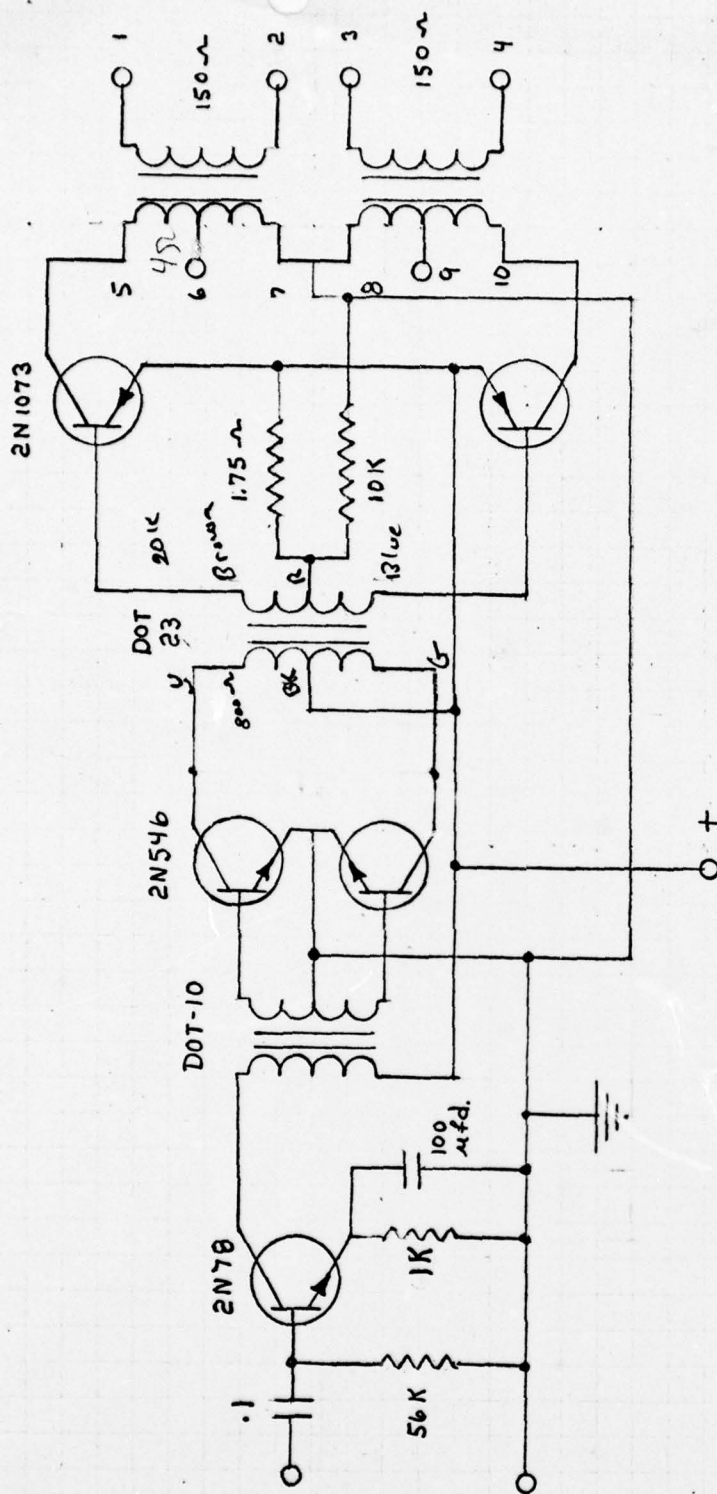


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FREQUENCY DISPLACEMENT TRANSPONDER

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